Options for Industrial Temperature Measurement During Process Cooling

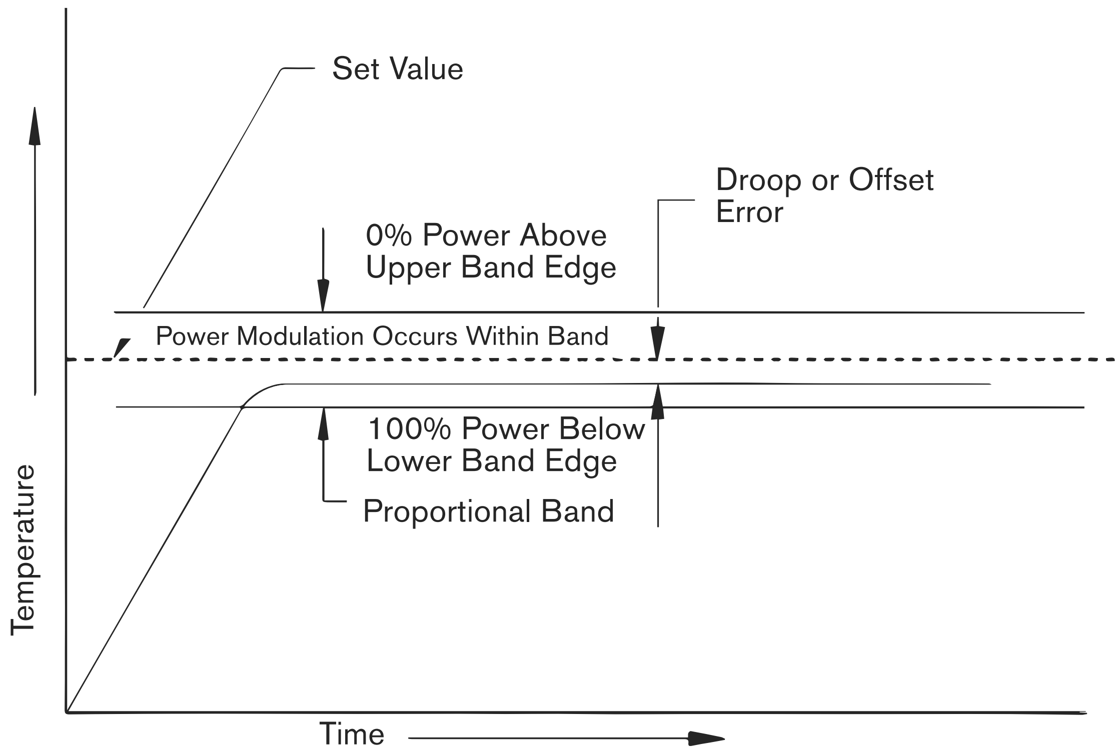
A primer on thermocouples — the most widely used temperature-measurement devices — also explores instruments to control temperature in industrial processes.

By Wayne Hayward, Athena Controls

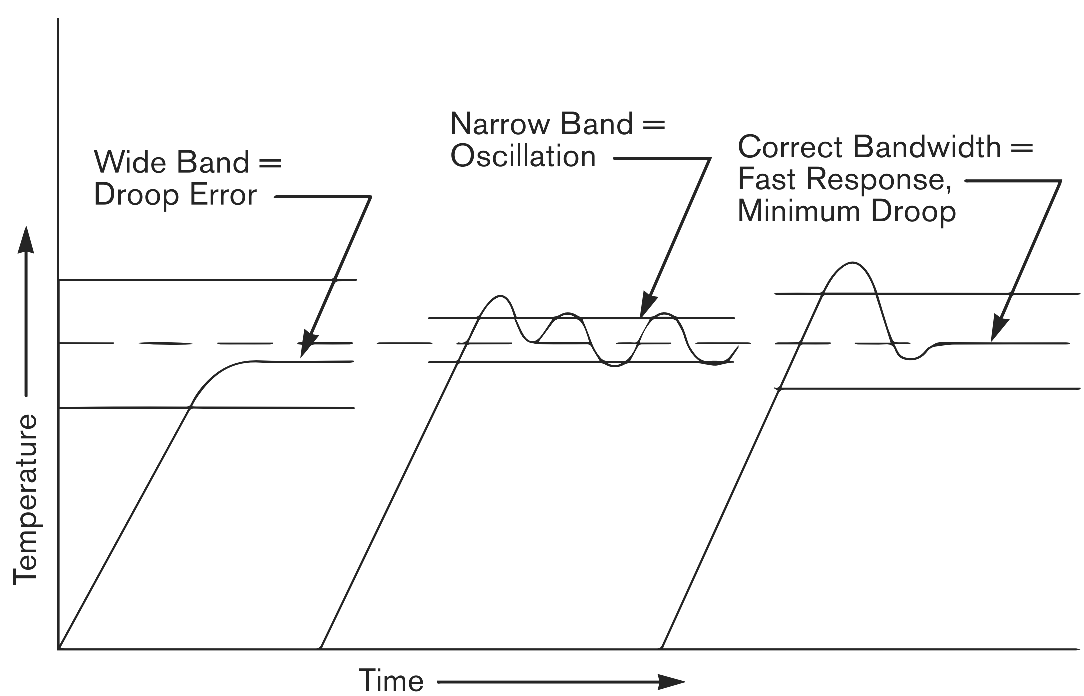
The versatile thermocouple is the most widely used industrial temperature-measurement device. Thermocouples are made by joining two pieces of dissimilar wire, and they can be sized by the gauge of wire used. When using a thermocouple, the temperature measurement occurs only at the actual interface between the two metals comprising the thermocouple, so the measurement area can be as small – or as large – as needed. It is critical that the wires are well insulated and similar all the way to the reading junction. Any missing insulation, or a junction with extension wire of dissimilar material, will become a new thermocouple and source of error.

Thermocouples are offered in many materials, and each pair has different characteristics of temperature range and voltage. The voltage produced by the thermocouple is always small – in the millivolt range – and is nonlinear. Deriving the temperature from the voltage produced requires that the output be matched to a lookup table or fed through a polynomial curve formula to return an actual temperature. Table 1 shows some common thermocouple sets and their basic parameters. Types J, K and T are the most commonly used in industrial processes with Type J being the most popular.

Proportional Control



Proportional Bandwidth



Proportional-only controllers may be used where the process load is fairly constant and the setpoint is not frequently changed.

Thermocouples and wires are offered in packages and insulations to handle the assortment of applications; consequently, many probes and sheath materials are offered. Probes are a type of packaged device where the temperature sensor – typically a thermocouple – is sealed inside a tube constructed of stainless steel or other materials. Probes can be open or closed depending on the application.

Like the thermocouple probe itself, thermocouple wire is supplied with options for insulation, wire size and cable protection. The wire comes in two grades: extension grade and thermocouple grade. Typically, the extension grade is not as precisely controlled for material content; as a result, it is less expensive.

All thermocouple wire is prepared as

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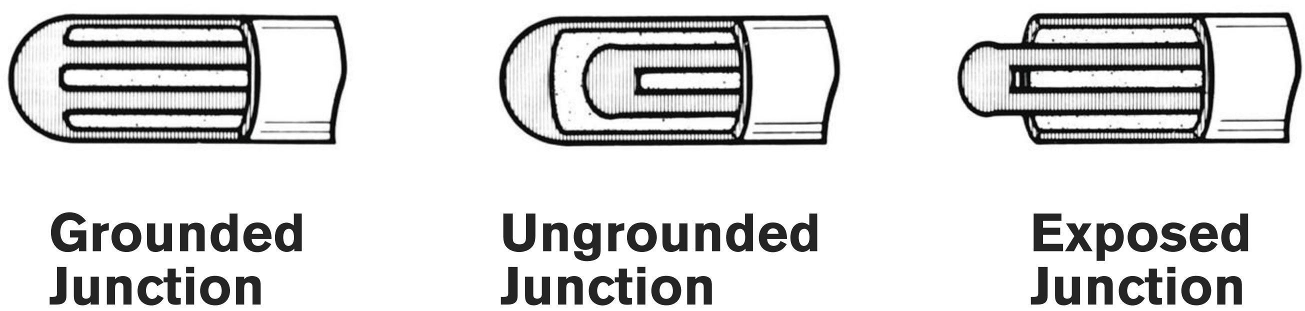
Thermocouple Specifications

Calibration Code	Typical Applications	Conductor & Characteristics		Recommended Temperature Range	Standard Limits of Error
		Positive	Negative		
J	- Suitable for vacuum, reducing or inert atmospheres - Reduced life in oxidizing atmosphere - Iron oxidizes rapidly above 1000°F, so only heavy-gauge wire is recommended for high temperatures - Bare elements above 1000°F should not be exposed to sulfurous atmospheres	Iron (Magnetic)	Constantan (Nonmagnetic)	32 to 1400°F	±4.0°F (±2.2°C) or ±0.75%*
Jx	- Compensating extension wire for Type J calibration	White	Red		±4.0°F (±2.2°C)
K	- Recommended for continuous oxidizing or neutral atmospheres - Mostly used above 1000°F - Subject to failure if exposed to sulfur - Preferential oxidation of chromium in positive leg at certain low oxygen concentrations causes "green rot" and large negative calibration drifts that are most serious in the 1500 to 1900°F temperature range	Chromel (Nonmagnetic)	Alumel (Magnetic)	32 to 2300°F (0 to 1260°C)	±4.0°F (±2.2°C) or ±2.0%*
Kx	- Compensating extension wire for Type K calibration	Yellow	Red		±4.0°F (±2.2°C)
T	- Usable in oxidizing, reducing or inert atmospheres as well as vacuum - Not subject to corrosion in moist atmospheres	Copper (Yellow Metal)	Constantan (Silver Metal)	-328 to 700°F (-200 to 371°C)	±1.8°F (±1.0°C) or ±0.75%*
Tx	- Compensating extension wire for Type T calibration	Blue	Red		±1.8°F (±1.0°C) or ±0.75%*
E	- Recommended for continuous oxidizing or inert atmospheres - Highest thermoelectric output of common calibrations	Chromel	Constantan	32 to 1600°F (0 to 871°C)	±3.06°F (±1.7°C) or ±1.0%
Ex	– Compensating extension wire for Type E calibration	Purple	Red		±3.06°F (±1.7°C)
R	- Recommended for high temperature - Requires nonmetallic protection tube and ceramic insulators - Long-term high temperature use causes grain growth and mechanical failure - Negative calibration drift caused by rhodium diffusion to pure leg as well as from rhodium volatilization	Platinum 13% Rhodium	Platinum	32 to 2700°F (0 to 1482°C)	±2.7°F (±1.5°C) or ±0.25%*
S	- Same as Type R calibration but output is lower - Also susceptible to grain growth and drift	Platinum 10% Rhodium	Platinum	32 to 2700°F (0 to 1482°C)	±2.7°F (±1.5°C) or ±0.25%*
RSx	- Compensating extension wire for Type R and Type S calibration	Copper (Black)	Alloy 11 (Red)		±9°F (±5°C)
B	- Same as Type R calibration but output is lower - Also susceptible to grain growth and drift	Platinum 30% Rhodium	Platinum 6% Rhodium	1600 to 3100°F (870 to 1705°C)	±0.5%*
Bx	- Compensating extension wire for Type B calibration	Gray	Red		±7.6°F (±4.2°C)
C(WS)	- For very high temperature applications in inert and vacuum atmospheres	Tungsten 5% Rhenium	Tungsten 26% Rhenium	32 to 4200°F (0 to 2315°C)	±8.0°F (±4.4°C) ±1%*
L	- Noble metal combination that approximates the Type K calibration but has much improved oxidation resistance - Should be treated as any noble metal thermocouple	Platinel II	Platinel II	32 to 2543°F (0 to 1395°C)	±0.150mv to ±0.315mv
N	- Modern nickel-based alloy similar to Type K calibration but offering lower drift and longer life at high temperatures	Nicrosil	Nisil	32 to 3200°F (0 to 1260°C)	±4.0°F (±2.2°C) or ±0.75%*
Nx	- Compensating extension wire for Type N calibration	Orange	Red		±4.0°F (±2.2°C)
Nickel-Moly	- Used in hydrogen applications - Cycling causes excessive grain growth	NiMo (Nickel -18% Molybdenum)	Nickel (Nickel-0.8% Cobalt)	32 to 2250°F (0 to 1232°C)	

*Stated tolerance value or percentage – whichever is greater. For percentages given, the tolerance (in °C) is calculated for a given temperature by multiplying the temperature (in °C) by the stated percentage.

Measuring Junctions



When using a thermocouple, the temperature measurement occurs at the actual interface between the two metals comprising the thermocouple, called the junction. The measurement area can be as small or large as needed. The wires must be well insulated and similar all the way to the reading junction.

a duplex wire. This means that there are two insulated wires inside an outer sheath, which contains one of each of the materials required for the appropriate thermocouple. For example, a Type T thermocouple wire would contain one copper wire and one copper-nickel alloy (Constantan) wire while a Type J thermocouple would contain one iron wire and one Constantan wire. The choice of insulation materials is dictated by the temperature of the environment in which it will be placed.

Table 1 shows the typical temperature limits of some standard thermocouple configurations. The temperatures listed are considered to be the extremes of the operating ranges. Accuracy of thermocouples is based on the purity of the wire and the wire junction, but it is helpful to understand the theory behind thermocouples to appreciate the right selection of thermocouple for the application. Precise measurements of the current, resistance and electromotive force were made as part of an investigation of thermoelectric circuits that resulted in the establishment of several basic laws.

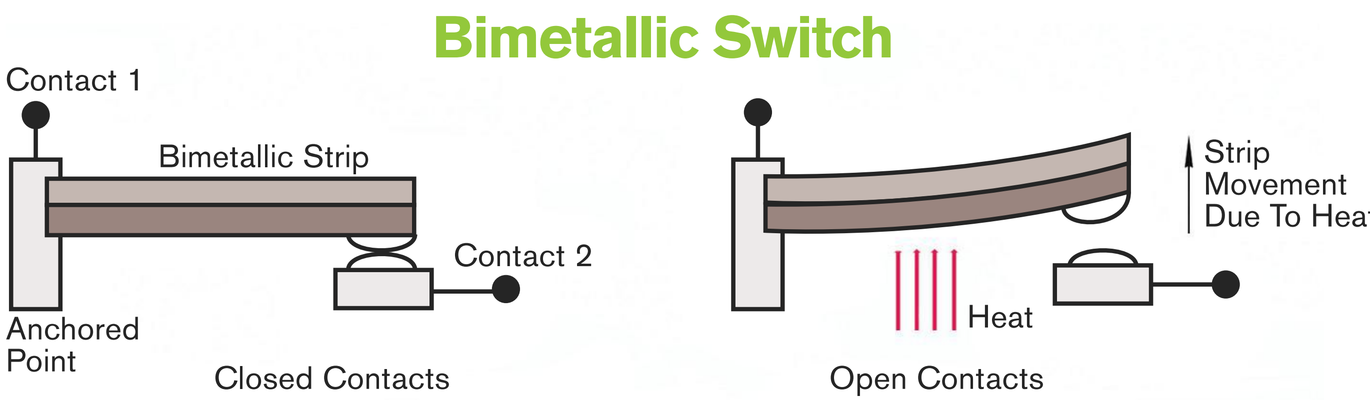
Semiconductor Probes

Semiconductor probes are the third main category of probe. Like a resistance probe (covered in the first part of this article series), they require a current or voltage supply to create a reading. But, this is where the similarity ends.

A semiconductor probe is essentially a temperature-variable resistance device that converts the change in resistance to a change in current. These devices typically do not have the accuracy of an RTD due to manufacturing tolerances; however, they are extremely cost effective for large-volume applications. They have a relatively large initial tolerance, or absolute offset, but this is countered by a high level of repeatability. Because they are not as accurate as an RTD or thermocouple, they have not found favor in many modern manufacturing applications.

Noncontact Devices

Noncontact temperature sensors typically consist of optical devices that detect and measure radiant heat. Measuring this



The earliest control systems were simple switches that used bimetallic elements. By placing a bimetallic element where its expansion motion can cause a contact to be made or broken, and attaching a wire to the element and contact, a simple temperature switch is created.

radiation makes it possible to determine the temperature of the object, both up close or from a vast distance.

Single-Reading Devices. Single-point reading devices are worth a mention, but they really only apply to temperature measurements of large objects (or at least the outside surface of said object. When using single-reading devices, it is helpful if there is a significant temperature difference between the object and its surroundings.

Single-reading devices work by allowing the heat radiation from an object to strike an infrared-sensitive element via a system of lenses. These systems require that the user know the spectral emissivity of the material for which the temperature is being measured in order to obtain an accurate reading.

Camera Field Devices. There are several types of camera field-temperature sensors. Generally, they are similar to a digital camera but they light in the infrared range of the light spectrum. The different types are distinguished by the wavelength range of infrared measured. These include near infrared (with wavelengths from visible light to 1000 nm) and far infrared (with wavelengths over 1000 nm). These devices take pictures of objects and display the varying temperatures as different intensities or colors visible to the human eye.

Types of Control

Measuring the temperature is just half of the equation. What you do next – to either increase, decrease or stabilize the process temperature – is a critical part of the control cycle. Several types of control, which use different methodologies to effect control, are available. The following is a short summary. For brevity's sake, this article will only consider one zone of control.

On/off control – where the output of the control is simply switched on or off as needed – is the most basic control method. On/off control has two states: fully off and fully on. To prevent rapid cycling, some hysteresis is added to the switching function. During operation, the controller output is on from startup until temperature set value is achieved. After overshoot, the temperature then falls to the hysteresis limit, and power is reapplied.

On/off control can be used where:

- The process is underpowered, and the heater has little storage capacity.
- Where some temperature oscillation is permissible.
- On electromechanical systems (compressors) where cycling must be minimized.

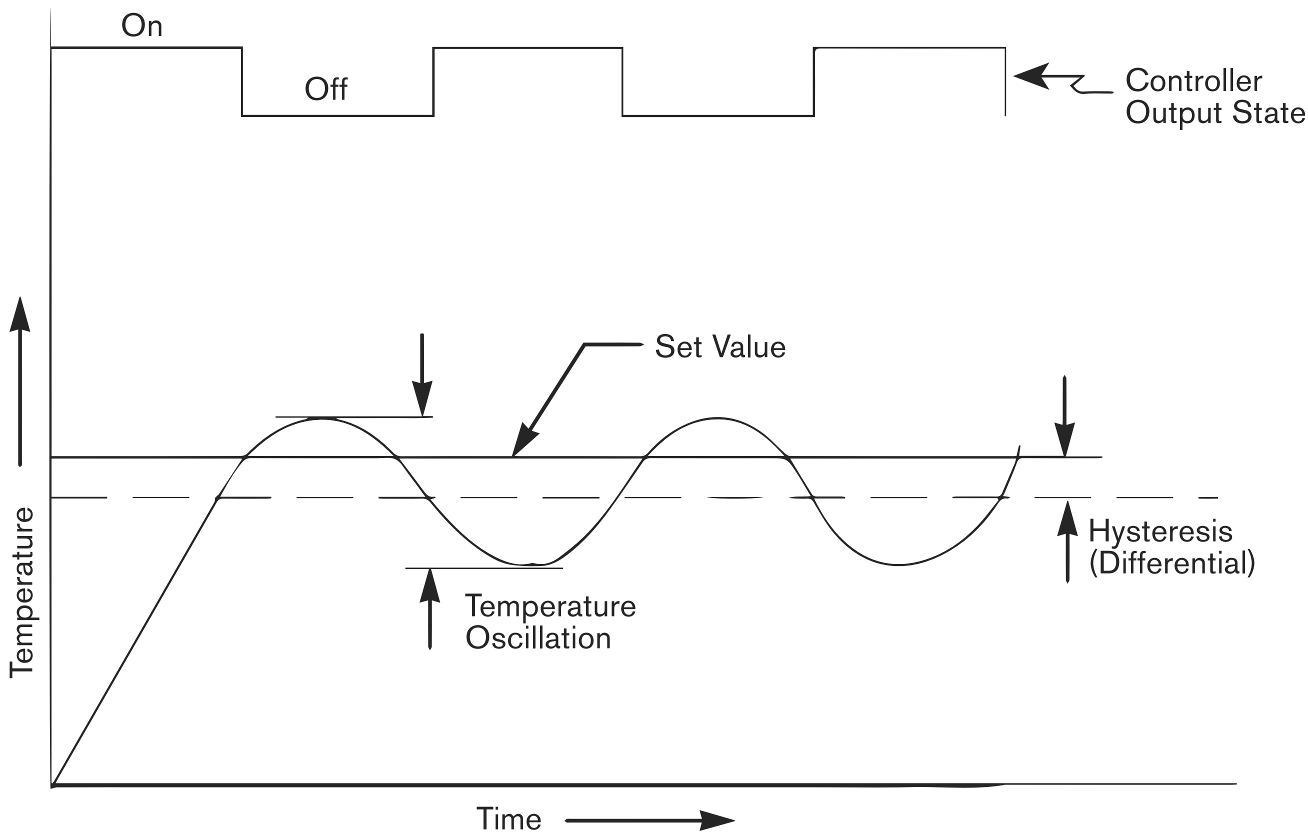
Proportional control is another basic control method. It measures a command signal and subtracts a feedback signal, creating an error signal. Proportional controllers modulate power to the process by adjusting their output power within a proportional band. The proportional band is expressed as a percentage of the instrument span and is centered over the setpoint. At the lower proportional band edge and below, power output is 100 percent. As the temperature rises through the band, power is proportionally reduced so that at the upper band edge and above, power output is 0 percent. Proportional controllers can have two adjustments:

- Manual reset.
- Bandwidth (gain).

Manual Reset. Allows positioning the band with respect to the setpoint so that more or less power is applied at setpoint to eliminate the offset error inherent in proportional control.

Bandwidth (Gain). This adjustment permits changing the modulating bandwidth to accommodate various process characteristics. High gain, fast processes require a wide band for good control without oscillation. Low gain, slow-moving processes can be managed well with a narrow band to on-off control. The relationship between gain and bandwidth is

On-Off Control



On/off control is the most basic control method, where the output of the control is simply switched on or off as needed.

expressed inversely:

$$\text{Gain} = \frac{100\%}{\text{Proportional Band in \%}}$$

Proportional-only controllers may be used where the process load is fairly constant and the setpoint is not changed frequently. Three options are:

- Proportional with Integral (PI), automatic reset.
- Proportional with Derivative (PD), rate action.
- Proportional Integral Derivative (PID).

PI Controls. Integral action moves the proportional band to increase or decrease power in response to the temperature deviation from setpoint. The integrator slowly changes power output until zero deviation is achieved. Integral action cannot be faster than the process response time or oscillation will occur.

PD Controls. Derivative moves the proportional band to provide more or less output power in response to rapidly changing temperature. Its effect is to add lead during temperature change. It also reduces overshoot on startup.

PID Controls. This type of control is useful on difficult

processes. Its integral action eliminates offset error while derivative action rapidly changes output in response to load changes.

The earliest control systems were simple switches that used bimetallic elements. By placing a bimetallic element where its expansion motion can cause a contact to be made or broken, and attaching a wire to the element and contact, a simple temperature switch is created.

It is easy to see how such a simple switch could have many applications. This basic on/off temperature control system is still in use today where changing the gap to the contact changes the set temperature at which it will make contact.

Today, there are plenty of capable controllers that provide sophisticated and varied types of control, including dedicated PID controllers, PLC controllers and PC controllers. Selection is mostly determined by the application and process. **PC**

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Learn More about Industrial Temperature Sensing and Control

"Classifying Temperature-Measurement Devices," the first part of this two-part article series, addressed the different types of temperature-measurement devices and covered thermometers, thermistors, thermopiles and RTDs. To read that article, visit **www.process-cooling.com/articles/90029-classification-of-temperature-measurement-devices.**